AN EVALUATION OF BEACH NOURISHMENT ON THE LAKE SUPERIOR SHORE

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ABSTRACT

In 1983, a demonstration project was initiated at Wisconsin Point on Lake Superior to evaluate the beach nourishment disposal option for "clean" harbor sediments. Previously, the State of Wisconsin prohibited open-water disposal of harbor dredge materials because of concern about possible environmental degradation. This study reports the effectiveness of the project for disposing of dredged materials and reducing shoreline erosion, and the environmental soundness of using Great Lakes harbor sediments to nourish beaches.

During the dredging and nourishment operations, changes in the physical beach, beach materials and benthos, and near shore water quality were monitored, and suitability of the dredged material for beach nourishment was measured. Deposition of dredged materials resulted in significantly increased beach materials. Although samples of dredged materials showed some were not suitable for the intended purpose based on EPA guidelines, the beach substrate was not altered nor water quality measurably affected by the nourishment project. Surveys of the benthos population indicated no adverse impact on the community and no significant disruption of beach use by the public was observed.

Although the demonstration project revealed no measurable detrimental impacts, beach nourishment has limited potential at this time because of the possible contamination levels in dredged materials. Proper classification of harbor sediments for safe use and/or disposal is an important issue for future study.

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INTRODUCTION

To protect the chemical quality, physical appearance, and biological productivity of its waters, Wisconsin has closely regulated the dumping of any materials into its lakes or streams, including its boundary waters. Material dredged from lake and river bottoms must be disposed of on land or in a containment facility. In 1979, the Wisconsin Coastal Management Program estimated a backlog of dredging work of 400,000 yd^3. But finding or building a proper site for this disposal can be difficult and transporting dredged material is costly; therefore other possible alternatives have received consideration. Beach nourishment—adding sand to beaches—is one way of using some of the dredged material and reducing disposal costs, while slowing shore erosion.

In 1956, beach nourishment was recognized as a potentially desirable form of shore protection by the U.S. Army Corps of Engineers (COE), primarily on ocean beaches. The early 1970s saw the first uses of dredged material for beach nourishment, and between 1977 and 1981 material from 25% of the Corps' dredging projects was used for this purpose. In a comprehensive review of the effects of dredging and dredge spoil disposal in estuaries, Morton (1976) found four types of impacts of unconfined disposal: alteration of circulation patterns by spoil mounds; redistribution of sediments; changes in the chemistry of sediments and overlying waters; and remobilization of contaminants by resuspension and biologic uptake.

Relatively few beach nourishment projects have been done on the Great Lakes. The first projects simply compensated for the impacts of navigation, and no evaluation of environmental impacts were made. Later a more thorough evaluation of beach nourishment was undertaken by Nester and Poe (1982) on Lake Huron. Their study showed no changes in sediment particle size distribution, water quality, or populations of bottom-dwelling organisms or fish that could be attributed to the nourishment project.

On Lake Superior, the effects of beach nourishment were less clear. The immediate local effects of near shore unconfined disposal in Lake Superior were measured when material classified by the U.S. Environmental Protection Agency (EPA) as "unpolluted" was placed in 12 ft of water off Minnesota Point, Duluth. Water quality decreased significantly, with several indicators exceeding Minnesota standards (Hotvet 1975).

Kiellor and Ragotzkie (1976) studied Lake Superior harbor and near shore sediments and assessed the potential impacts of in-lake disposal of dredged material. They concluded that beach nourishment was a potentially beneficial use of dredged material (predominately coarse to medium sand) on eroding areas of Wisconsin Point. However, Duluth-Superior harbor dredged material was found to vary considerably in quality, with some sediments containing potentially harmful amounts of trace metals, in particular mercury.

Concern over open water disposal of polluted dredge material led finally in 1975 to the prohibition of such material in the Great Lakes boundary waters of Wisconsin.

Another major concern has been the increase in shoreline erosion on Wisconsin Point, which has exposed old solid waste placed by the City of Superior in a dump on the land side of Wisconsin Point.

More information on disposal options was needed, and agreement was reached through the Wisconsin Coastal Management Council to evaluate the beach nourishment disposal option. The demonstration project reported here was set up to determine if the use of tributary sediments to nourish beaches is an effective and environmentally sound means of disposing of dredged materials, and at the same time reducing shoreline erosion.

DESCRIPTION OF STUDY AREA AND ENVIRONS

Wisconsin Point, chosen as the site for the demonstration project, is located just outside of Duluth-Superior harbor at the western tip of Lake Superior (Fig. 1). Together with Minnesota Point, Wisconsin Point forms the longest freshwater bay mouth sand bar in the world. The area is owned by the City of Superior, and is used by local residents for water-oriented recreation.

The only building on the point is the University of Wisconsin-Superior's Lake Superior Study Center located at the tip of the point. There is a small dock at the study center. Jetties and an arrowhead breakwater protect the Superior entry to the harbor. Four groins and about 300 yards of large rock riprap protect an area near the east end of the point. The groin field and riprap were installed to protect the former city landfill from continued lake erosion into Lake Superior.

Lake Superior is the largest body of fresh water in the Western Hemisphere. The lake is oligotrophic with exceptionally high water quality. Its small outflow means a very low flushing rate (183 years). Biologically, Lake Superior is noted for its extremely low productivity.

The littoral drift (lake bottom material in the surf zone) on the south shore of Lake Superior and Wisconsin Point is generally sands and gravels sorted out of the eroded bluff materials and sediments carried by streams into Lake Superior. The fine materials (silts and clays) are carried offshore into deep water.

The largest waves of the south shore of Lake Superior come from the northeast (because of the longer fetch). Furthermore, most of the large waves occur in the fall and the spring—when most large storms occur. Since Lake Superior shoreline is ice covered from January to April spring storm waves usually don't reach the south shore. Summer is relatively free of large storms, so most littoral drift movement and damage to beach and bank occur during the fall storms.

Large waves also cause the beach to erode offshore to form sand bars. The sand bars are important because they cause the waves to break offshore rather than on the beach (which would cause further erosion). Small waves during late spring and summer months move littoral drift back on the beach.

The net direction of littoral drift in the west end of Lake Superior is to the west. The littoral drift eventually stops on the bay mouth bar which protects Superior-Duluth harbor. Most of this littoral drift comes from tributary streams and bluff erosion on the south shore (Wisconsin shore), since the north shore (Minnesota shore) is very rocky.

The Nemadji River is the most important source of coarse sediments in the Duluth-Superior harbor area, because it is eroding former glacial lakebed. Other tributary streams do not contribute significant amounts of coarse sediments to the littoral drift. Streams flowing into Lake Superior between Bark Bay and Wisconsin Point have smaller percentages of sand and gravel. In addition, most of their watersheds are small. The St. Louis River, although it has a very large watershed, contributes almost no coarse sediments.

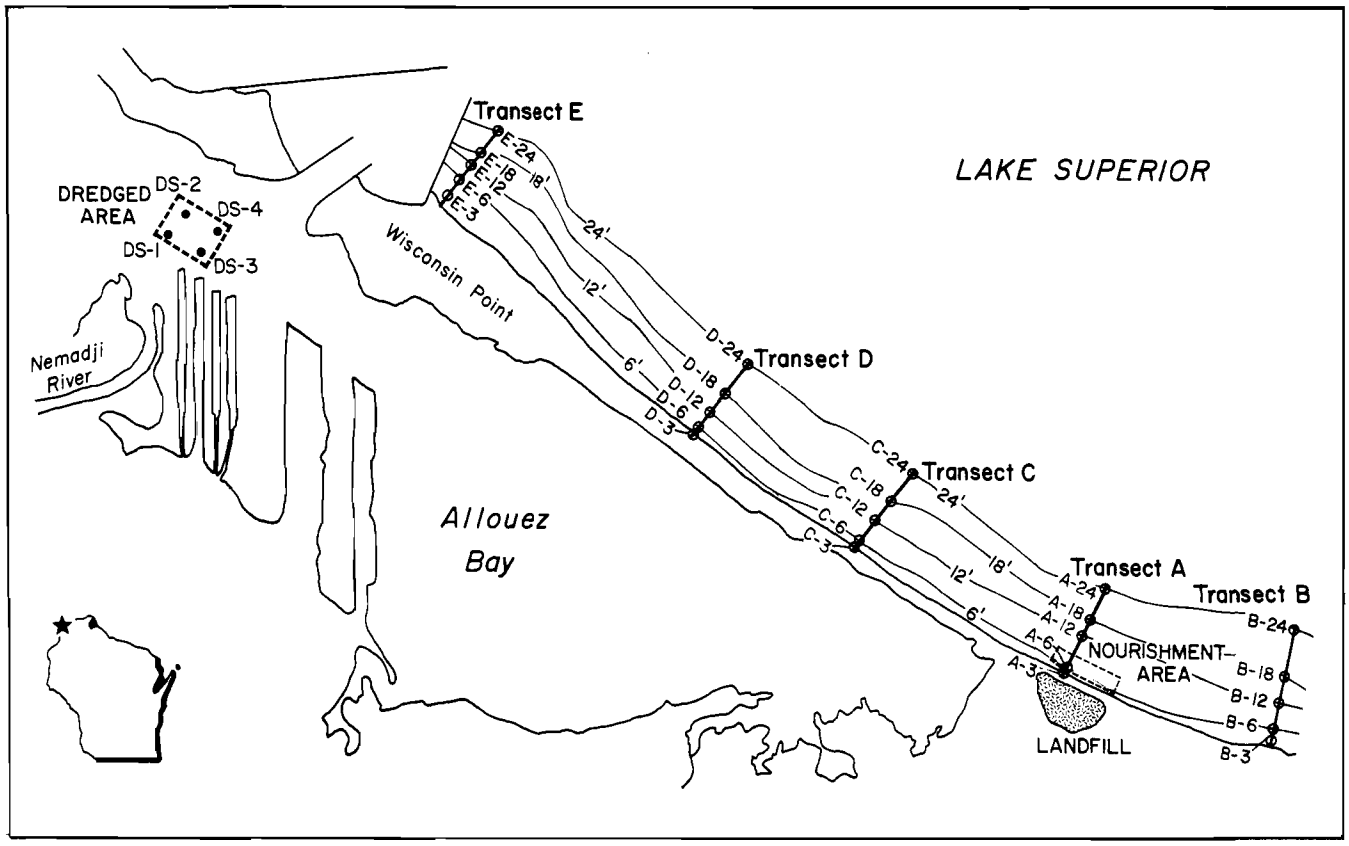
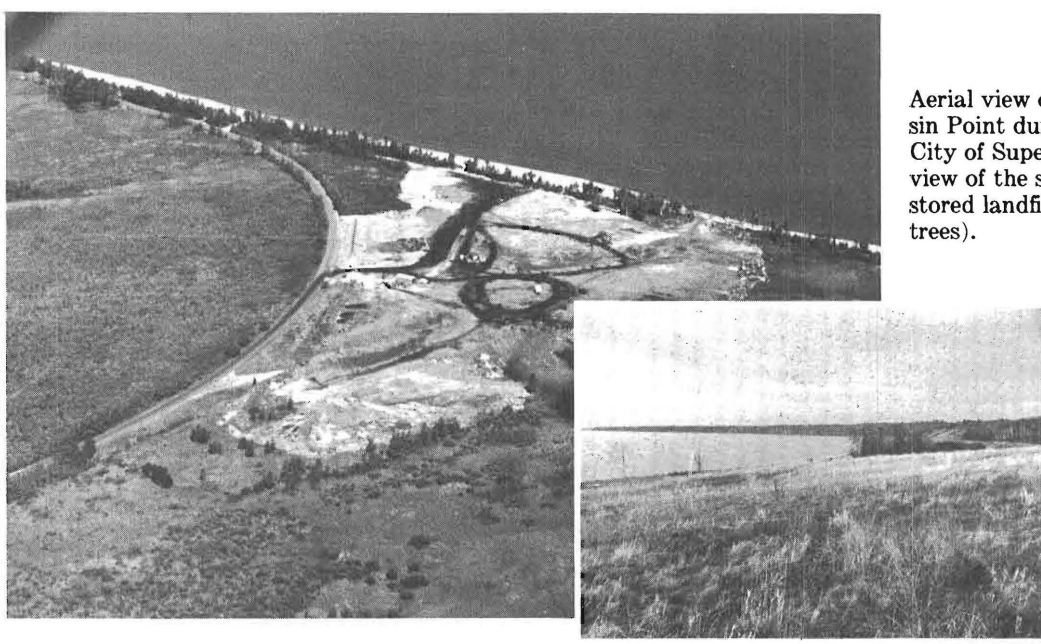


FIGURE 1. *Location of Wisconsin Point, dredged area, and sampling transects.*

View of riprap along shoreline. Groins can be seen in distance.

Typical groin. Note placement perpendicular to shoreline.



Aerial view of the landfill on Wisconsin Point during its operation by the City of Superior in the 1960s. Inset: A view of the shoreline from the restored landfill area (note lack of trees).

PROCEDURES

Nourishment Operation

The dredging and placement of materials at Wisconsin Point took place between 14 September and 1 November 1983. Contract letting complications delayed the nourishment operation to the fall storm season. The COE contractor, Durocher Dredge and Dock Company, used a clam shell dredge to remove material from Superior harbor near the mouth of the Nemadji River. The material was loaded onto barges and towed to the nourishment site (Fig. 1). A smaller clam shell crane on an anchored barge was used to place the dredged material in the lake. Original plans called for unloading 50-60,000 yd^3 of dredged material along a 2,600-ft reach in the near shore area. However, the contract let by the COE limited disposal to a 1,300-ft stretch immediately lakeward of the groin field. The material was unloaded 400-450 ft offshore in 5-6 ft of water.

Beach Physical Changes

The change in the near shore profile and the rate and volume of movement of dredged material placed in the near shore area were monitored. A survey baseline, tied to known benchmarks, was established in the fall of 1982 (Fig. 2), and preoperational data were gathered 11-15 October 1982. Water depth soundings were taken by handline and with sonar equipment. Site photographs were taken at least monthly.

Pre- and post-operation surveys were conducted and depth sounding data converted to a bathymetric map (Fig. 6) and near shore profile (Fig. 7). The map shows 5-ft contours for comparison of bathymetry before and after the operation. Near shore profiles are cross sections of the study area. They extend from the shoreline out into the water to the 20-ft contour. The profiles were used for calculating the volume of sediment movement.

Harbor Sediments

Superior harbor sediments used in the Wisconsin Point beach nourishment project were sampled twice prior to the beginning of our study, in 1975-76 and in 1982. Details on sampling procedures, handling methods, and analytical results and interpretations can be found in various EPA (1977) and DNR (1983) documents.

Approximately one month before dredging started, we also collected sediment samples in the Superior harbor, near the mouth of the Nemadji River inside the area designated for dredging. Surface sediment samples were collected at four different locations with a ponar dredge (Fig. 1). Nemadji River sediments and red clay bluff materials, which are natural sources of sediment to Superior harbor and Wisconsin Point, were sampled at four locations shown in Figure 3. The samples were sent to the State Laboratory of Hygiene for chemical analysis and to the Department of Transportation laboratory for particle size analysis.

The dredged material was extensively sampled while dredging was in progress. With the cooperation of the dredging contractor, the dredging crews collected a one-quart sample of nearly every barge load of material that was towed to the deposition site. Each sample was therefore representative of about 250 cubic yards of material. The samples were stored in the refrigeration unit on the tugboat until we could pick them up and send them in for laboratory analysis. For chemical and particle size analyses, the 191 individual barge load samples collected were composited (blended and subsampled) into 14 samples, each representing 10-15 barge loads of dredged material.

Beach Material and Benthos

All beach material and benthic invertebrate samples taken before, during, and after the nourishment opera-

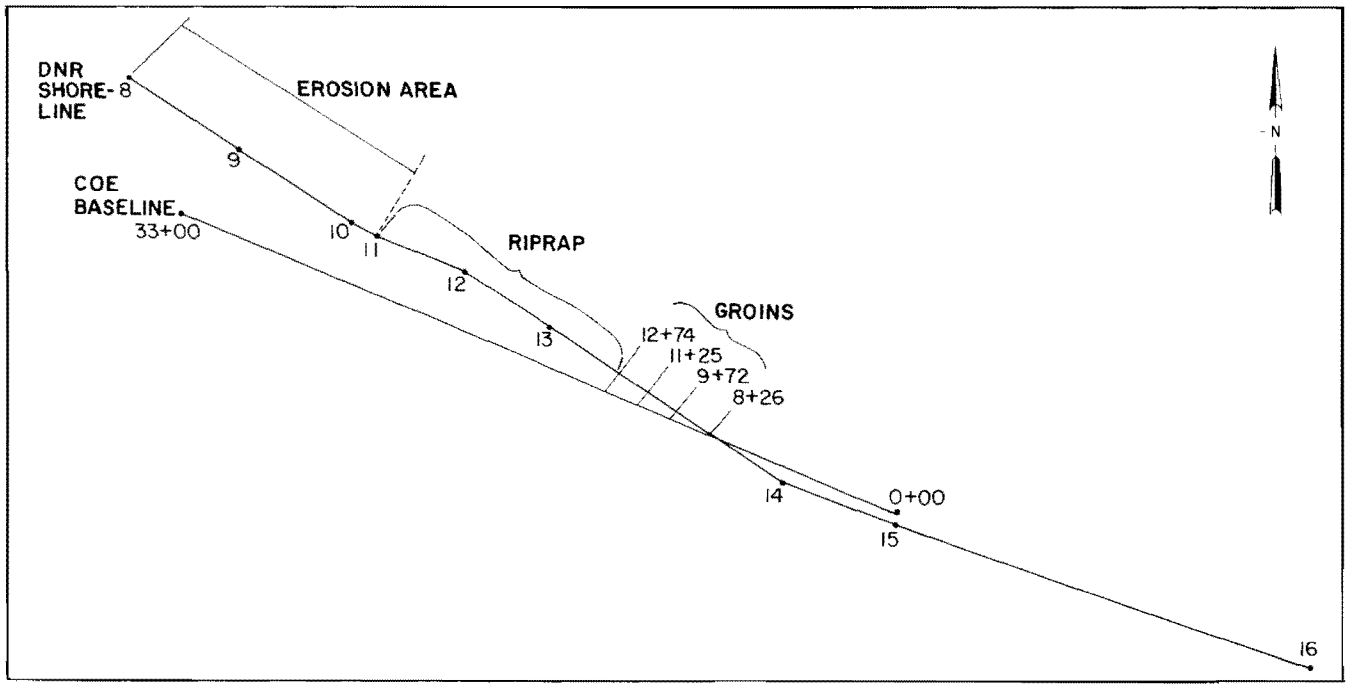
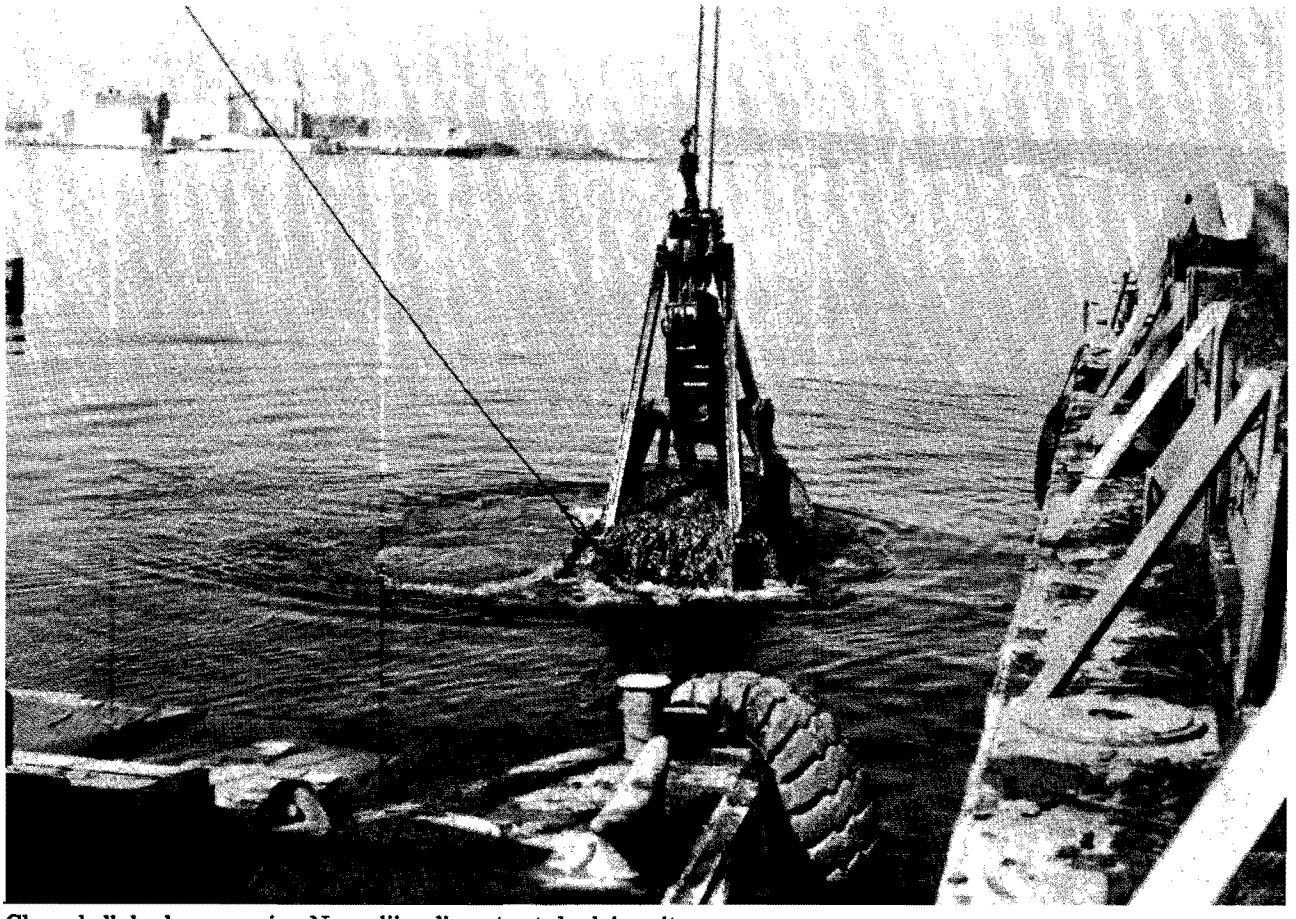
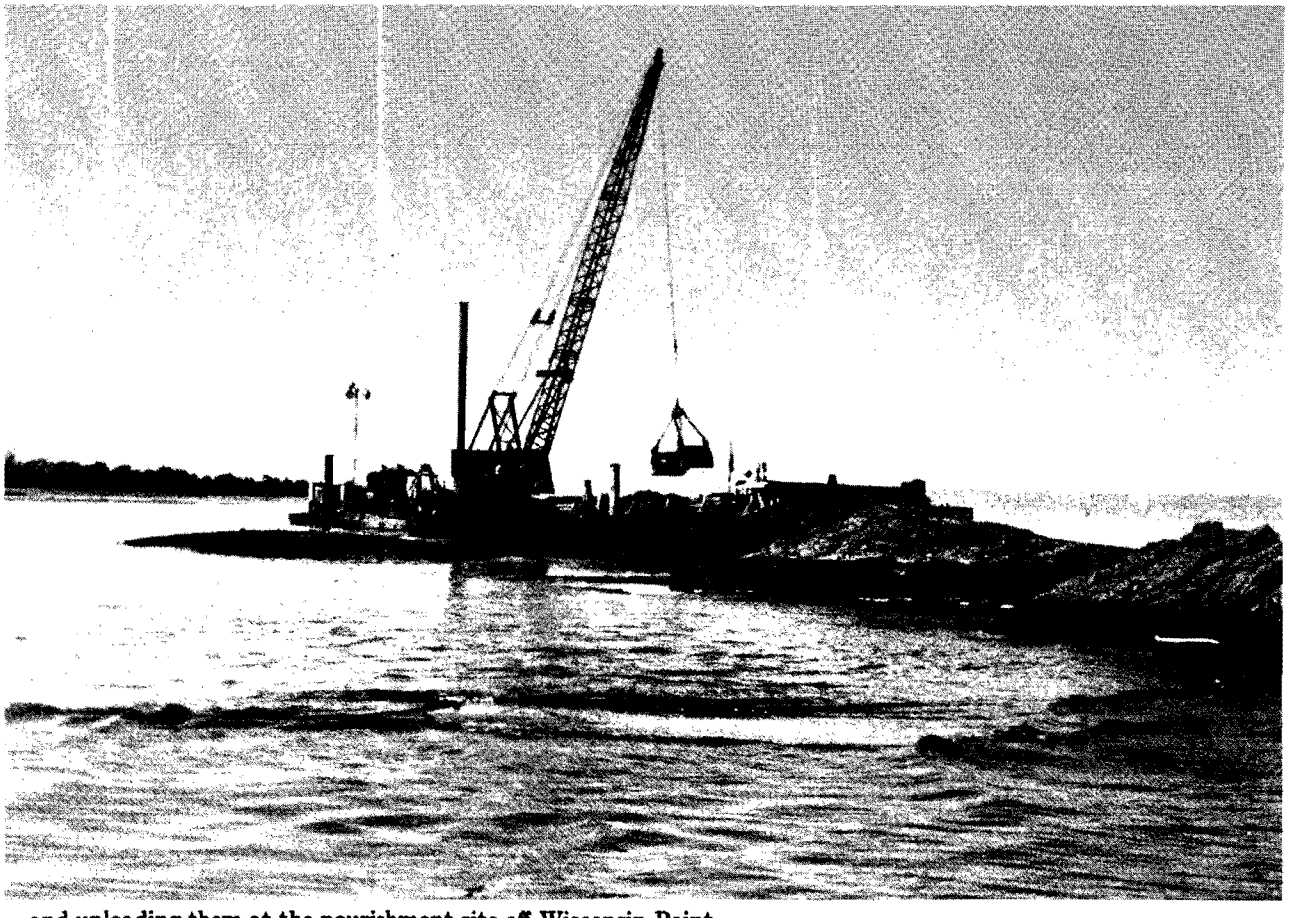


FIGURE 2. *Survey baselines established in the fall of 1982.*



Clam shell dredge removing Nemadji sediments at dredging sites ...



... and unloading them at the nourishment site off Wisconsin Point.

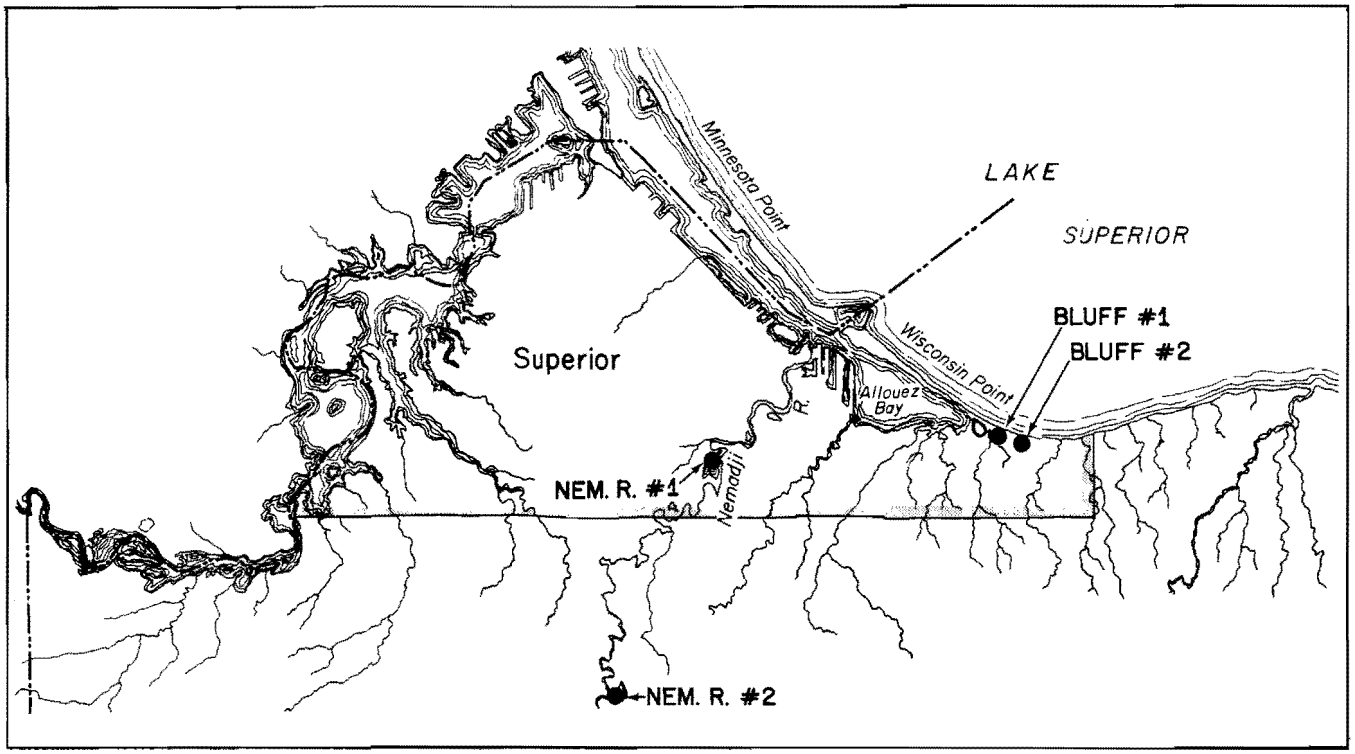


FIGURE 3. *Nemadji River and bluff sampling sites.*

tion were collected along five transects (Fig. 1). Sampling stations were established before treatment on the 3-, 6-, 12-, 18-, and 24-ft depth contours. The same sites were sampled during and after the operation even though water depth changed at some locations. Not all sites were sampled on every sampling trip, because climatic conditions forced changes in scheduled sampling or because the investigators judged it unnecessary to sample some locations.

Bottom samples were collected exclusively with a ponar dredge. The material for physical and chemical analysis was prepared on-site according to procedures specified by the laboratories performing the analyses. In order to determine sample variability, four separate benthic samples were taken at the same location on several occasions. At the laboratory, benthic organisms were concentrated with a 30-mesh sieve, sorted, and preserved in 70% ethanol for identification and counting. Chironomidae and Amphipoda were identified to genus and species, respectively, and the remainder to the lowest possible taxonomic classification.

Treacherous ice conditions prevented collection of some data during the winter following the nourishment operation.

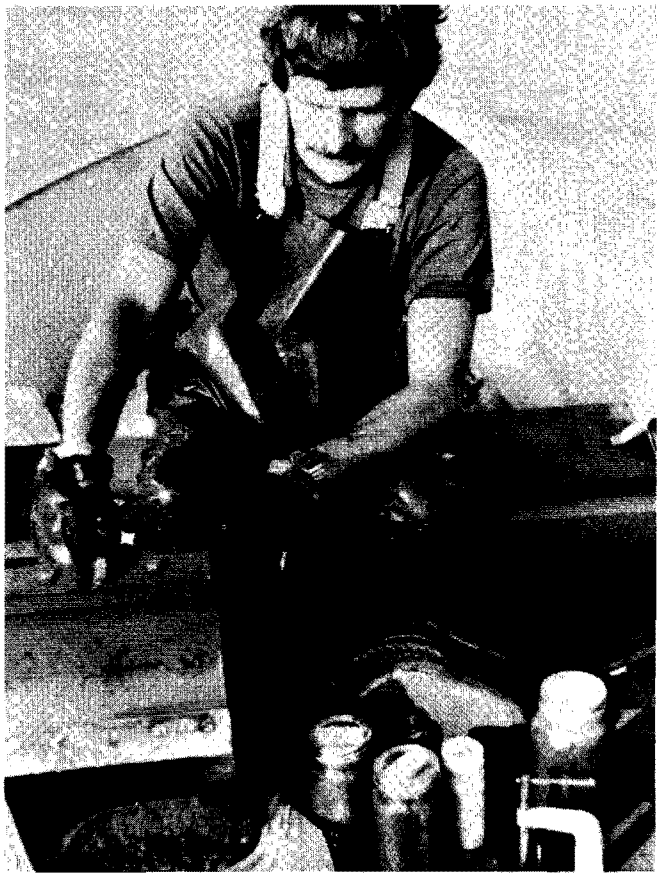
Water Quality

Water quality samples were collected at the same sites as bottom samples before, during, and after the treatment project. Measurements made in the field included temperature, pH, alkalinity, conductivity, color, turbidity, Secchi, and chlorophyll *a*. Samples for analysis at the State Laboratory of Hygiene were drawn from about one ft below the water surface, and delivered to the laboratory within 24 hours.

Laboratory Analyses

Sediment analyses performed at the State Laboratory of Hygiene included total phosphorus, total kjeldahl nitrogen, chemical oxygen demand, oil and grease, arsenic, barium, cadmium, chromium, copper, iron, mercury,

Near shore water quality measurements were made along 5 transects before, during, and after the nourishment operation.



Benthic invertebrates and bottom material samples were collected with a ponar dredge.

manganese, nickel, lead, zinc, PCB, percent volatile solids, and percent moisture. The same set of tests were run on water samples, as well as soluble phosphorus, ammonia, nitrate and nitrite, suspended solids, turbidity, calcium, magnesium, potassium, sodium, sulfate, and chloride. All analytical procedures at the State Laboratory of Hygiene are EPA approved and a rigid quality assurance program is followed. Detailed information on operating procedures at the State Laboratory is available upon request.

The Wisconsin Department of Transportation laboratory performed particle size analysis of dredged material and beach material samples. Percent of gravel, coarse sand, fine sand, silt, and clay was determined for each sample as follows: gravel: pass 3-inch mesh sieve, retained in #10 sieve; coarse sand: pass #10, retained in #40; fine sand: pass #40, retained in #200; silt: pass #200, retained in 0.002 mm; clay: pass 0.002 mm.

RESULTS AND DISCUSSION

DREDGED MATERIAL CHARACTERISTICS

Particle Size

Particle size analysis of the samples taken on the barges showed considerable variation in the material (Fig. 4). Most of the material was sand-gravel (67% average), but a significant amount was silt-clay (33% average). While some of the barge loads were almost entirely sand, others were made up of nearly 50% fine particles. Use of material consisting of a high percentage of fine particles is generally not desirable for beach nourishment because (1) if contaminants are present in sediments they are normally associated with the fine particles, (2) the fine silt-clay particles are easily suspended and readily transported from the nourishment site, and (3) fine materials are potentially more detrimental to water quality and biota (Kiellor and Ragotzkie 1976, Ill. Geol. Serv. 1981).

Chemical Composition

In the samples collected at the dredging site on 9 August 1983 a number of constituents exceeded the EPA's limits for unpolluted Great Lakes harbor sediments (Table 1). The three samples with the highest silt-clay fraction (DS 1, 2, and 3) had the highest levels of pollutants, while the sample which was composed of the coarser material (DS 4) was the cleanest. The finer samples contained traces of mercury. No PCB's were found in any of the samples. Because of the collection method (ponar dredge), these samples contained only near-surface sediments. The bulk of the material that was used in the nourishment project was dredged from greater depths.

More representative data on the characteristics of the dredged material were obtained from barge samples taken during the operation (Table 2). Although all but one of the composite samples exceeded EPA's unpolluted category for at least one parameter, most of the material could be considered as satisfactorily "clean", based on the "multiple factor" assessment method used by EPA (U.S. EPA 1977).

This judgment was based also on results from the analysis of natural sediments. Samples from the red clay bluff soils sloughing into the lake at the base of Wisconsin Point, showed that levels of several metals were above EPA's unpolluted category guideline, as was the total phosphorus concentration (Table 3). One Nemadji River sediment sample, which was predominately silt-clay material, also exceeded the unpolluted guideline for some parameters. These results support the widespread opinion that these guidelines are not realistic for some parameters. Brown and Klump (1984) also found "contamination levels" exceeding the current guidelines in natural sediments and eroding bluff soils along the Lake Michigan shoreline at Kewaunee.

These new data will help in making necessary changes in the guidelines.

While the bulk of the dredged material was relatively free of contaminants, the first 25 barge loads contained concentrations of mercury in excess of 1 mg/kg. Under the EPA criteria, this material would have been classified as polluted and unsuitable for unconfined disposal. About 5,000-6,000 yd^3 or roughly 10% of the dredged material used in the operation was contaminated. It contained an estimated 23 lb of mercury. Because only trace amounts of mercury were detected in harbor sediments collected prior to dredging, and samples collected on the barges were not analyzed for several weeks, use of the contaminated material for this project could not have been prevented.

The origin of the mercury found in these materials is unknown. It can only be speculated upon. It was associated with materials that came from the upper sediment layers made up of a higher than average percentage of fine particles. The mercury was either contained in some sediment layer not sampled prior to dredging or was a very recent and localized surface deposit.

BEACH SEDIMENTS

Materials Movement

Deposition of the dredged material within the designated 1,300-ft nourishment area took place at a rate faster than natural lake currents could move it shoreward or lakeward. As a result, a

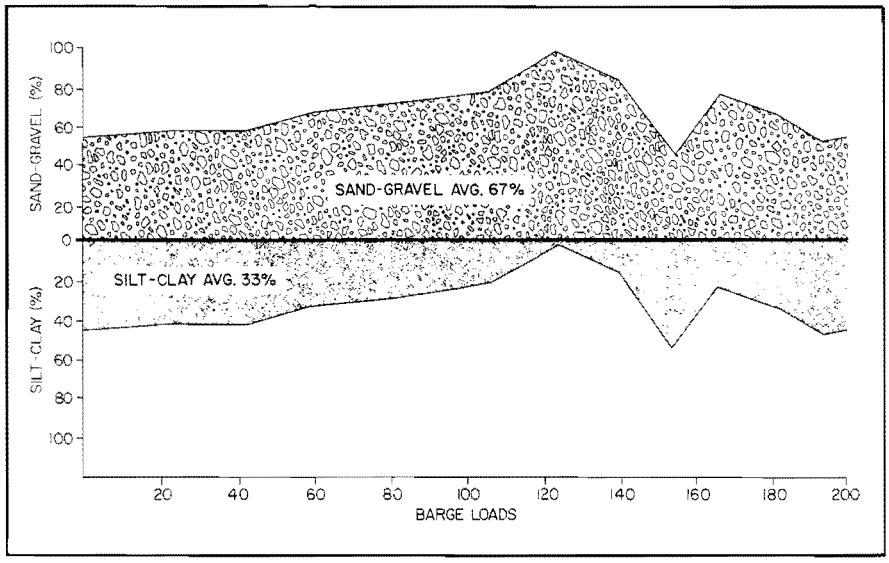


FIGURE 4. *Size analysis of barge material particles.*

Some of the dredged material was too fine-grained for a beach nourishment project. This barge load was mostly clay and silt.

temporary "island" of material built up off the groin field. Some of this island of dredged material remained visible to the end of the operation, and there were also large deposits noticeable between it and the groins and landfill. Thus, a temporary offshore breakwater was created which protected the shoreline and the landfill. A temporary groin effect resulted from this temporary offshore breakwater and accumulated littoral drift. This temporary effect caused new beach buildup updrift of the nourishment area as deposition progressed. At the completion of the project an estimated 33,000-40,000 yd^3 of the dredged material remained in place at the nourishment site. This estimate is based on the premise that the silt-clay fraction of the dredged material, or one third of the total of 50,000-60,000 yds^3 deposited, was dispersed lakeward into deep water.

Shortly after completion of the project in early November, a violent storm (17-year recurrence interval) oc-

TABLE 1. *Chemical analysis of sediments from the dredging site at the mouth of the Nemadji River.*[a]

Parameter[b]	EPA Classification of Great Lakes Harbor Sediments			Analysis of Dredge Site Samples Taken 9 August 1983			
	Unpolluted	Moderately Polluted	Heavily Polluted	DS-1	DS-2	DS-3	DS-4
Total phosphorus	420	420-650	650	599	528	415	167
Total Kjeldahl nitrogen	1,000	1-2,000	2,000	896	838	634	177
Cadmium (Cd)	—	—	6	<1	<1	<1	<1
Chromium (Cr)	25	25-75	75	29	38	22	9
Lead (Pb)	40	40-60	60	<5	<5	<5	<5
Zinc (Zn)	90	90-200	200	58	59	38	20
Copper (Cu)	25	25-50	50	30	30	16	11
Nickel (Ni)	20	20-50	50	24	26	14	<5
Barium (Ba)	20	20-60	60	106	120	66	28
Iron (Fe)	17,000	17-25,000	25,000	18,000	13,000	13,000	6,700
Manganese (Mn)	300	300-500	500	620	640	350	170
Mercury (Hg)	None	—	1	0.02	0.03	0.02	<0.02
Arsenic (As)	3	3-8	8	8.2	4.9	4.4	2.4
Oil/grease	1,000	1-2,000	2,000	108	116	158	<30
COD	40,000	40-80,000	80,000				
PCB (mg/l)	None	—	10	<0.05	<0.05	<0.05	<0.05
Volatile solids (%)	5	5-8	8				
Particle size (%)							
Gravel				—	—	4	26
Coarse sand				3	13	14	47
Fine sand				19	24	34	15
Silt				61	51	39	10
Clay				17	12	9	2

[a] Shaded values indicate that sample exceeded EPA unpolluted classification.
[b] All measurements in mg/kg except as indicated.

TABLE 2. *Physical and chemical analysis of dredged material sampled from barge loads.*

Parameter[a]	Comp. 1 (1-10)[b]	Comp. 2 (11-25)	Comp. 3 (26-42)	Comp. 4 (43-58)	Comp. 5 (59-76)	Comp. 6 (77-93)	Comp. 7 (94-107)	Comp. 8 (108-123)	Comp. 9 (124-139)	Comp. 10 (140-154)	Comp. 11 (155-166)	Comp. 12 (167-181)	Comp. 13 (182-194)	Comp. 14 (195-205)
Total P	510	430	400	340	360	300	300	150	220	460	350	320	440	410
TKN	570	660	590	480	470	400	390	88	200	770	420	460	660	620
Cd	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cr	19	19	14	19	20	9	9	<5	<5	23	9	10	14	14
Pb	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zn	38	42	39	30	31	21	17	8	14	47	28	27	39	32
Cu	16	17	15	12	13	9	8	3	6	19	10	12	16	15
Ni	10	14	9	10	15	<5	9	<5	<5	14	<5	<5	14	9
Ba	60	60	60	40	50	40	30	<20	30	70	40	50	60	50
Fe	16,000	15,000	15,000	12,000	13,000	8,800	5,000	6,400	7,100	19,000	9,400	11,000	15,000	14,000
Mn	310	310	320	230	230	160	56	52	120	360	210	250	380	310
Hg	1.91	1.43	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.03
As	4.0	4.1	4.3	3.8	4.6	4.2	3.9	2.6	3.2	6.9	3.9	3.6	4.9	5.0
Oil/grease	140	98	150	120	140	140	78	<60	67	170	85	110	120	100
COD	29,000	28,000	27,000	21,000	22,000	22,000	21,000	9,000	9,000	27,000	16,000	20,000	24,000	26,000
PCB (ug/g)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				
Vol. sol.(%)	2.9	2.7	2.5	2.2	2.2	1.9	1.8	1.2	1.1	2.9	1.9	2.0	2.6	2.3
Part. size (%)														
Boulders	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gravel	—	—	3	—	—	—	—	—	—	—	—	—	—	5
Coarse sand	5	6	3	1	1	3	4	10	7	4	9	7	12	16
Fine sand	52	49	54	66	69	71	75	88	78	40	67	59	39	35
Silt	33	35	34	26	25	20	16	1	10	41	17	25	36	33
Clay	10	7	9	7	5	6	5	1	5	15	7	9	13	11

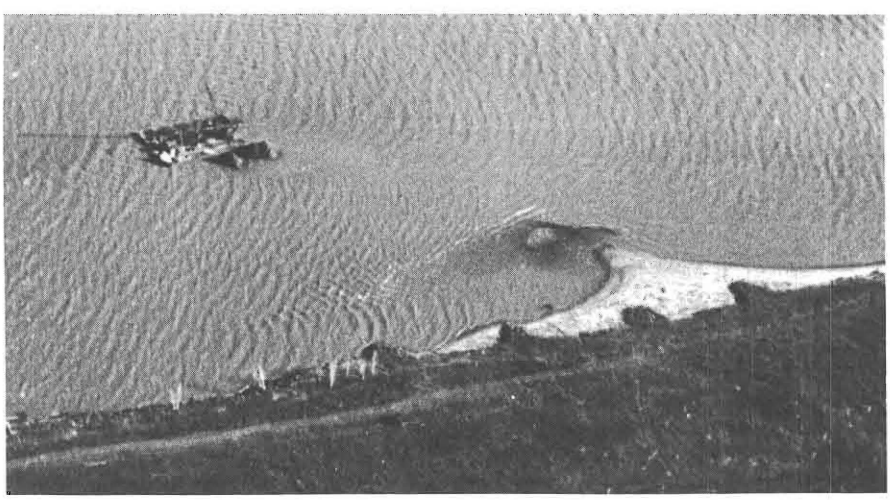
[a] All measurements in mg/kg except as indicated.
[b] Numbers in parentheses are the load numbers from which each composite was made.

TABLE 3. *Physical and chemical characteristics of Nemadji River sediments and Wisconson Point Bluff materials.*[a]

Parameter[b]	Bluff #1	Bluff #2	Nem. R#2	Nem. R#2
Total P	520	640	470	220
TKN	220	210	500	160
Cd	1	1	1	1
Cr	62	66	36	14
Pb	5	5	5	5
Zn	54	64	40	17
Cu	39	44	20	7
Ni	31	36	19	6
Ba	180	270	89	37
Fe	29,000	33,000	17,000	9,300
Mn	630	700	400	210
Hg	<0.02	<0.02	<0.02	<0.02
As	6.2	7.6	7.1	4.0
Vol. solids (%)	2.9	3.2	2.6	0.8
Particle size (%)				
Boulders	—	—	—	—
Gravel	—	—	—	—
Coarse sand	2	1	—	27
Fine sand	9	3	30	47
Silt	68	29	11	20
Clay	21	67	59	6

[a] Shaded values above EPA guideline for "unpolluted" harbor sediments.
[b] All measurements in mg/kg except as indicated.

The dredged material placed in front of the old landfill caused waves to break further offshore, expending erosion energy that otherwise would have been brought to bear on the shoreline.



Littoral drift accumulated in front of the groins following the deposition of sediments.

curred on Lake Superior that had considerable impact on the beach and near shore area. Waves were said to overtop portions of Wisconsin Point, and significant amounts of material were redistributed. This storm, occurring so soon after completion of the project, prevented measurement of dispersal of the material under normal conditions.

Comparison of bathymetric surveys taken before the operation and immediately after the storm indicates that the beach and near shore area contained an additional 64,375 yd^3 of material between stations 0+00 and 33+00 (Fig. 5), 43,000 yds^3 of which was in front of the landfill. About half of this increase in material can be attributed to the blocking of shore sediments, moved during the November storm, by the temporary offshore breakwater. Therefore, the dredged material breakwater exaggerated the intended beach nourishment objectives.

The last bathymetric survey taken in June 1984 indicated that there was still about 37,000 yd^3 more material in the beach and near shore area between stations 0+00 and 33+00 than existed prior to the operation. In June 1984 there was 27,000 yd^3 more material protecting the landfill than was there prior to the nourishment operation.

The bathymetric map showing changes in near shore bottom contours before and after the project indicates that those beach materials moved offshore during the winter and onshore in summer (Figs. 6, 7). It appears there was an unusual seasonal gain/loss in the vicinity of the groins-nourishment area (Fig. 5). In all other places along the baseline, the gains/losses are minor, thus indicating that the beach was stable.

Severe bank erosion took place west of the riprap shoreline at Pts. 9 and 10 (Fig. 8) after completion of the project. The November storm and the dredged material breakwater appeared to have caused the erosion to occur. A survey in May 1984 showed an estimated loss of about 1,400 yds^3 of bank material due to the erosion the previous fall. At Pt. 8, approximately 1,000 ft west of the end of the riprap, little bank erosion occurred.

Particle Size

The nourishment project had no appreciable effect on particle size of beach materials within the treatment zone. Along Transect A, composition of sediments was predominantly fine sand before, during, and after the nourishment operation (Fig. 9). The material at the 3- and 6-ft depths along Transect A (and also Control Transects B and

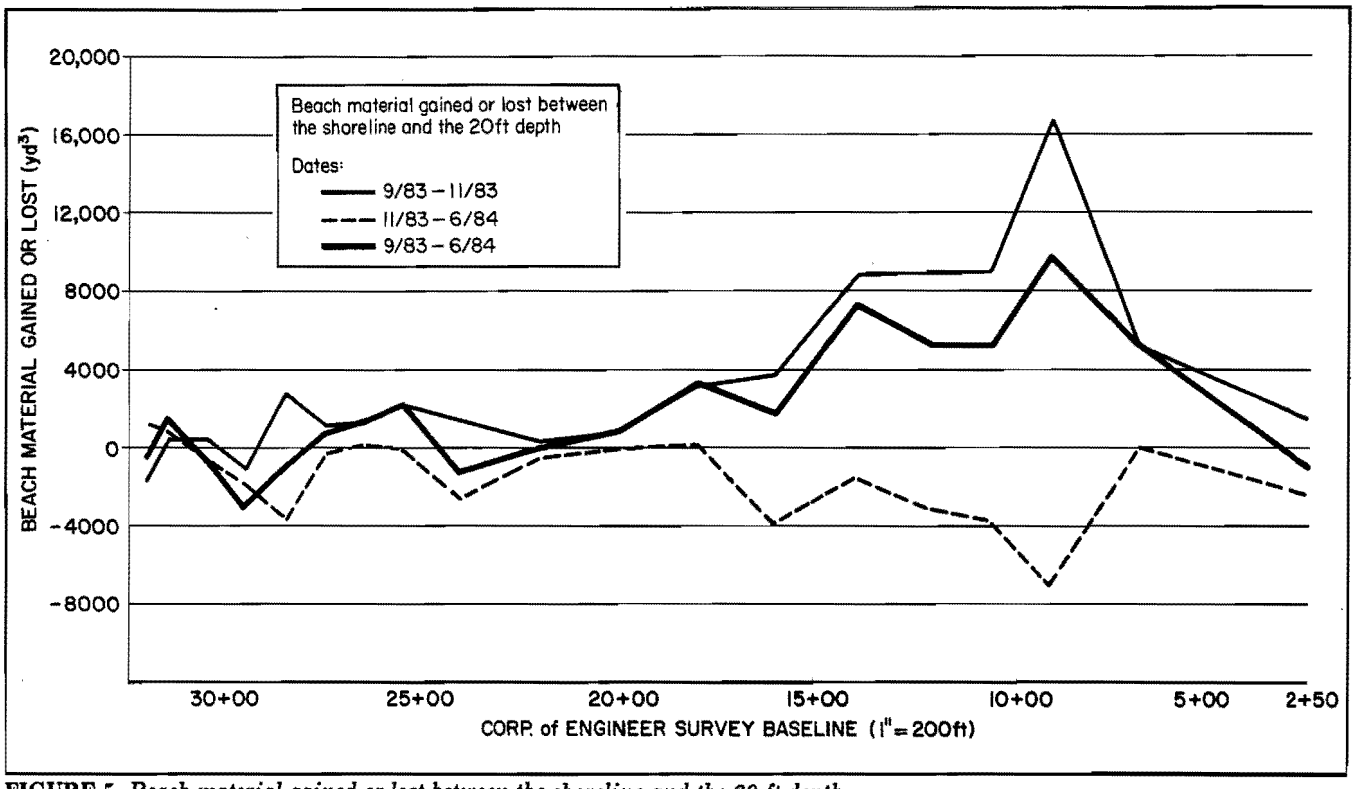


FIGURE 5. *Beach material gained or lost between the shoreline and the 20 ft depth.*

C) was slightly coarser during and after treatment than before. A shift toward more fine particles in the sediment during and after nourishment might have been expected because about one-third of the dredged material was silt-clay. However, the fine material apparently became immediately suspended during the unloading operation and never became part of the near shore sediment. Normal winnowing processes seemed to have taken place, resulting in rapid offshore movement of fine sediment. Samples collected at the 12-, 18-, and 24-ft depths on all transects always contained some fine sediment. Some of the fine particles in the dredged material could have been deposited at these depths.

Beach berm erosion at the downdrift end of the riprap (May 1985).

Chemical Composition

Chemical analyses of beach materials (Fig. 10) showed no changes in chemical composition as a result of the project. Levels of all measured constituents were the same before, during, and after treatment. Although a relatively small amount of dredged material used in the nourishment operation was found to contain mercury, no mercury was detected in any beach samples collected during or after the project. Other heavy metals were present only at low levels or in undetectable amounts.

The dredged material might have been expected to contain some oil and grease, due to shipping traffic or the dredging operation itself; however, oil and grease concentrations were low in the dredged material and below detection limits in beach sediments. Because no PCB's were found in any samples of dredged material before it was deposited, no PCB samples were collected at the project site after the operational phase.

WATER QUALITY

As a basis for determining impacts of the demonstration project on water quality, naturally occurring water quality conditions off Wisconsin Point were documented before the project began. In general, water quality in the near shore zone did not vary much during the year prior to treatment (Table 4), except for water clarity, which showed considerable variation (Fig. 11). The before-treatment ranges in

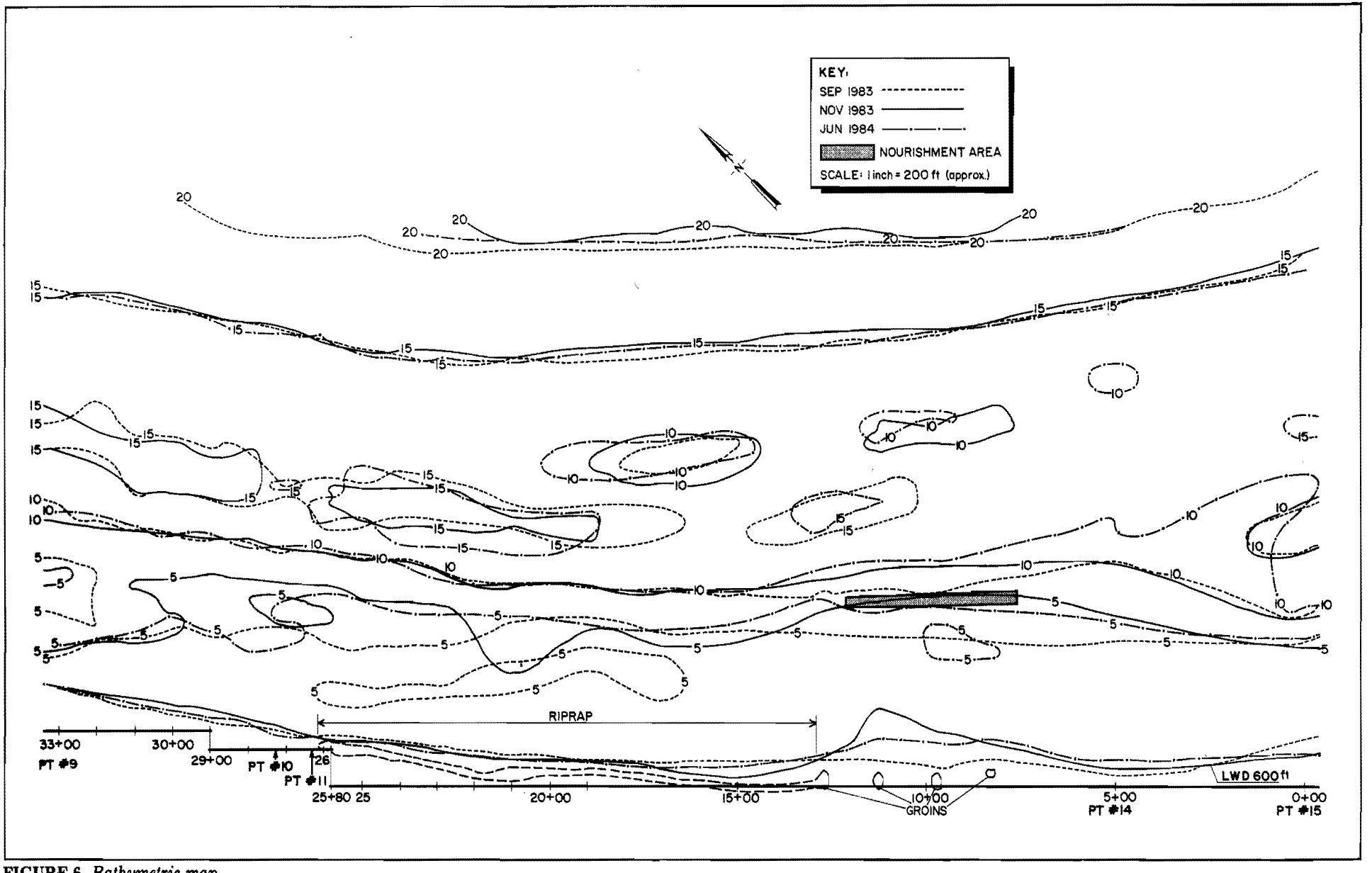


FIGURE 6. *Bathymetric map.*

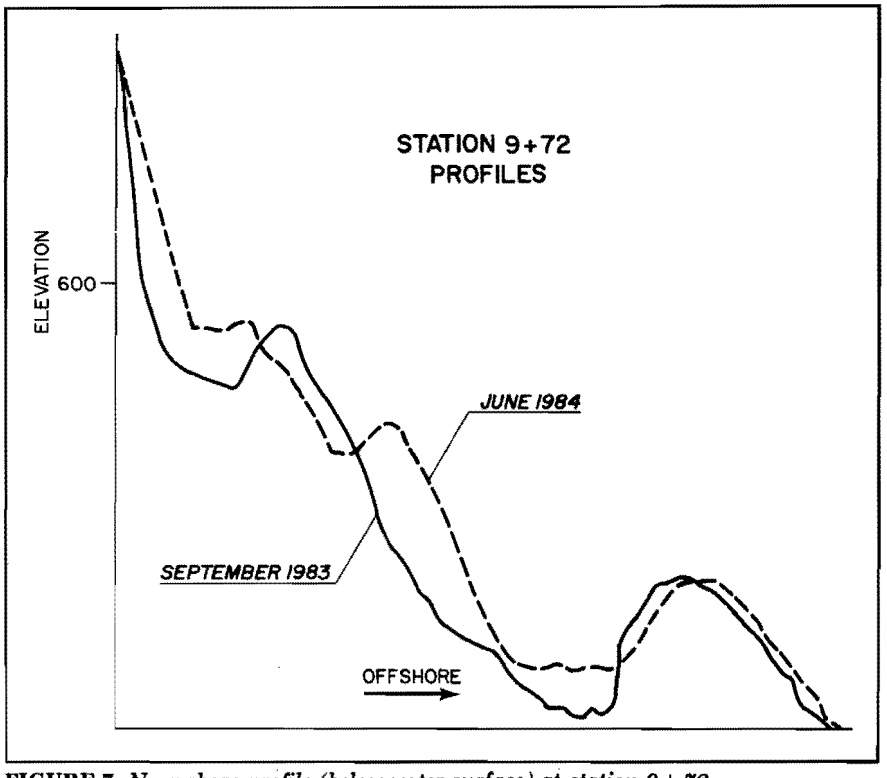


FIGURE 7. *Near shore profile (below water surface) at station 9+72.*

values for turbidity, suspended solids, color, and Secchi disc reading demonstrate the great differences in water clarity that occurred within the project area. Dramatic and often rapid changes in water clarity are a well recognized natural phenomenon along the Lake Superior shoreline. Weather conditions are the determining factor. During periods of calm or offshore winds, the water is usually very clear, but during storms or periods of strong onshore wind, bluff erosion and resuspension of bottom sediments causes the turbidity and "red clay" color characteristic of the Lake Superior shoreline.

Since the Superior harbor sediments used in this project were 33% silt-clay, the potential for creating turbidity was quite high but not unlike natural situations. Data collected on three different dates, 2 during and 1 after the nourishment operation show that water clarity was always within the normal range as established in 1982 (Fig. 11). On 26 September, about two weeks after treatment began, water clarity was somewhat lower along Transect A, in the treatment zone, and Transect C immediately downdrift from the treat-

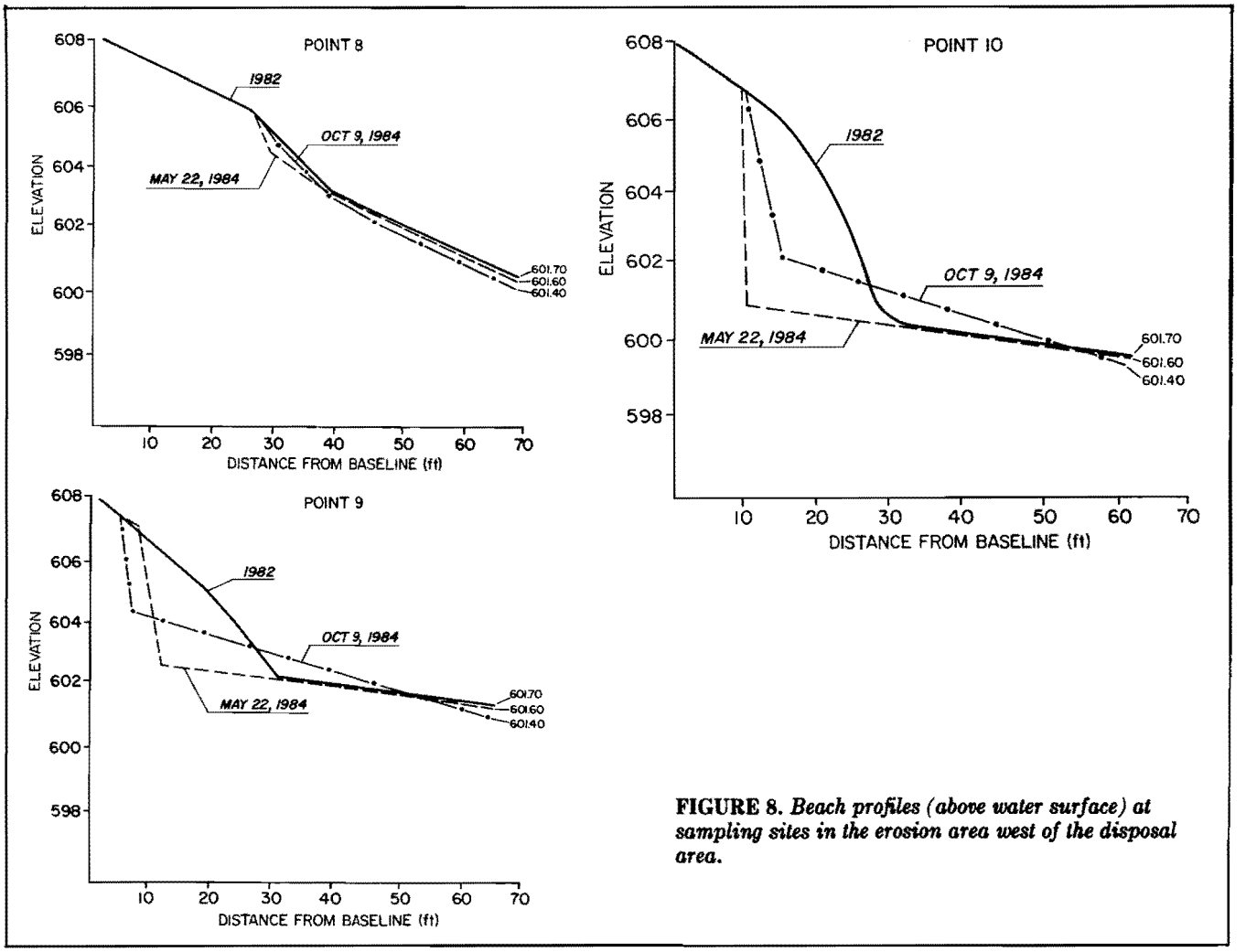
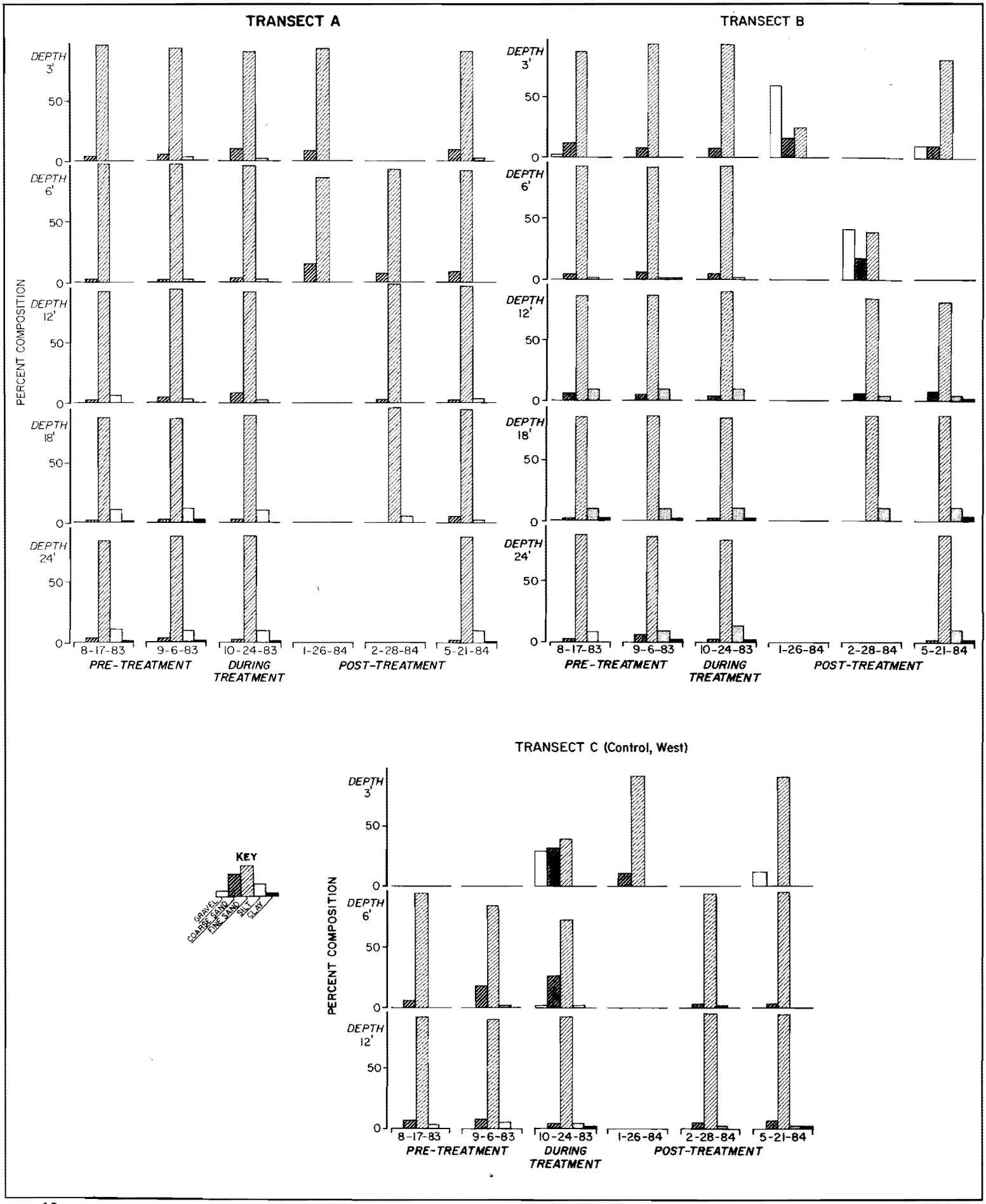


FIGURE 8. *Beach profiles (above water surface) at sampling sites in the erosion area west of the disposal area.*



16 **FIGURE 9.** *Sediment particle size before, during, and after treatment.*

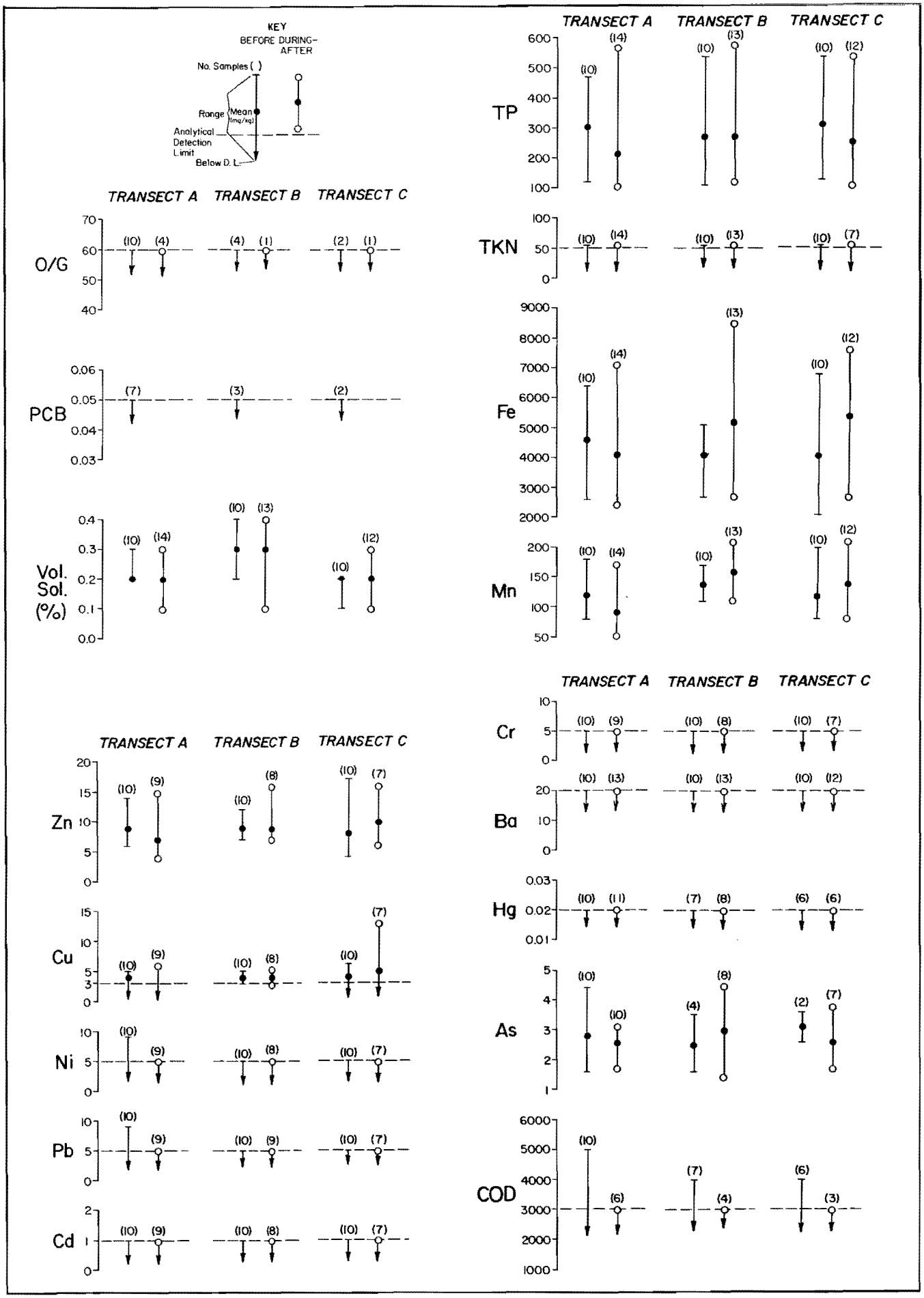
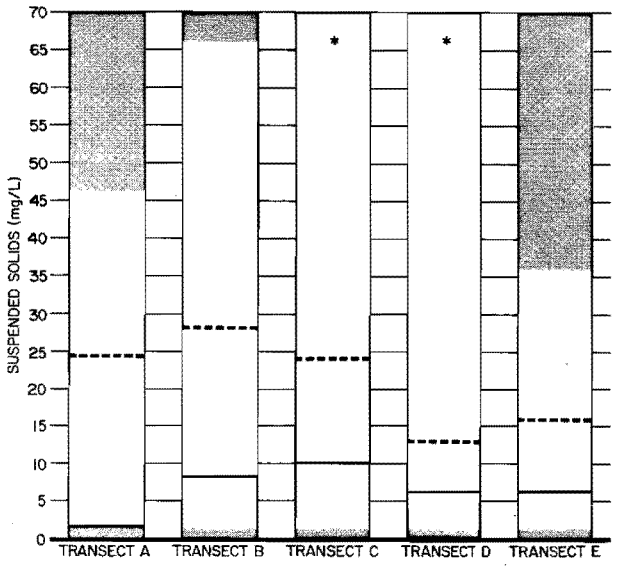
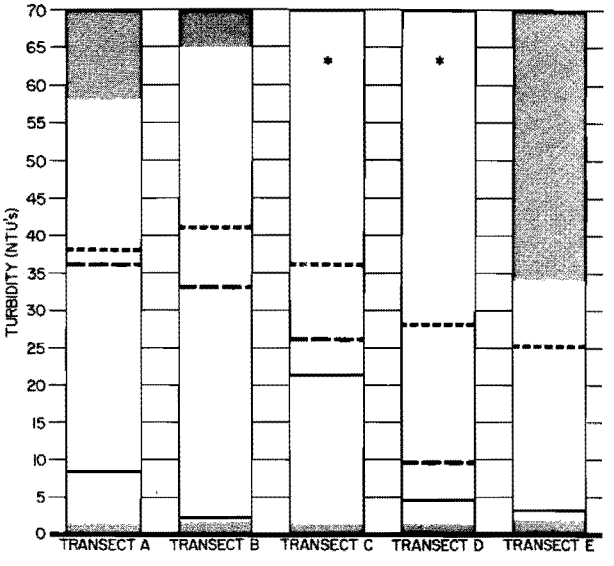
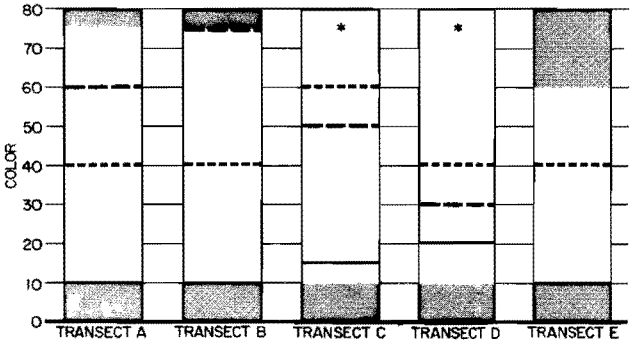
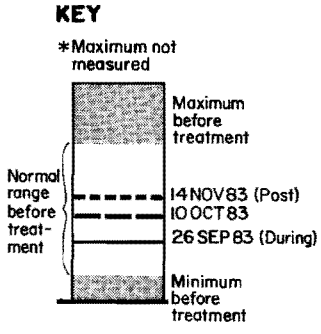


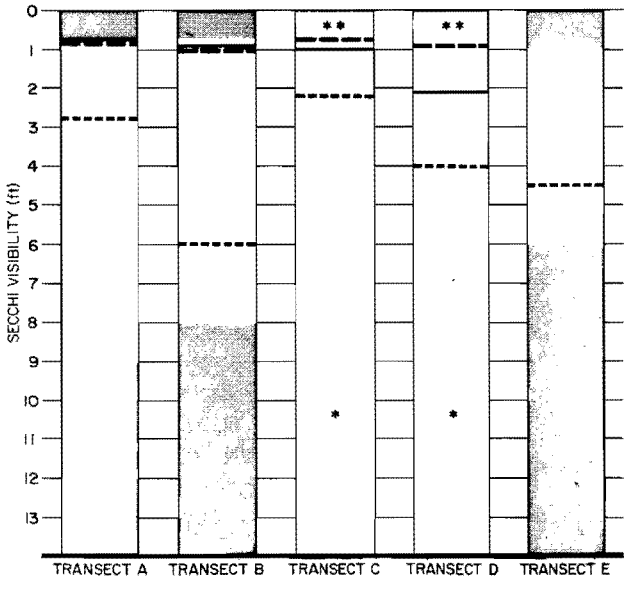
FIGURE 10. *Chemical analysis of beach sediments. (All values in mg/kg dry weight, except Vol. Sol. (%)).*











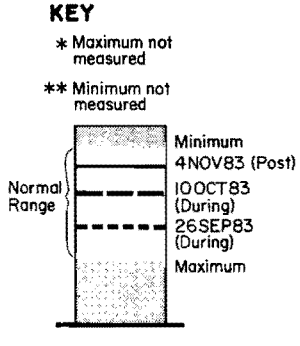


FIGURE 11. *Water clarity indicators before, during, and after the nourishment operation.*

TABLE 4. *Analysis of water quality near shore at the nourishment site on Wisconsin Point, before, during, and after the dredge disposal operation.*[a]

Parameter	Transect A Treatment Zone			Transect B South Control			Transect C North Control		
	Before	During	After	Before	During	After	Before	During	After
Total alk.	39-49(19)[b]	42-51(6)	46-49(3)	40-48(19)	43-51(6)	44-46(3)	40-45(9)	43-48(6)	45-48(3)
ph (SU)	7.1-7.5(19)	7.2-7.4(6)	7.2-7.3(3)	7.1-7.6(19)	7.2-7.3(6)	7.2-7.3(3)	7.1-7.5(9)	7.2-7.3(6)	7.2-7.3(3)
Cond. (MHos)	90-115(19)	90-130(6)	105-110(3)	87-110(19)	85-115(6)	90-105(3)	90-110(9)	83-110(6)	95(3)
Chl. A (ug/L)	1.9-13.5(19)	1.6-9.9(6)	4.1-5.8(3)	2.5-9.7(19)	1.1-6.9(6)	3.6-4.3(3)	2.3-6.1(9)	1.3-6.6(6)	3.5-4.1(3)
Tot. phosphorus	0.005-.054(19)	0.006-0.013(6)	0.024-0.034(3)	0.005-0.061(19)	0.004-0.009(3)	0.027-0.042(2)	0.008-0.028(9)	0.005-0.001(3)	0.028-0.034(2)
Sol. phosphorus	DL[c]-012(19)	DL(4)	0.006-0.007(3)	DL-0.011(19)	DL(3)	0.006-0.008(2)	DL-0.005(9)	DL(3)	0.006-0.007(2)
Tot. nitrogen	0.42-0.94(19)	0.48(3)	0.47-0.48(3)	0.43-0.78(19)	0.47-0.48(3)	0.47-0.48(2)	0.41-0.64(9)	0.48(3)	0.47-0.56(2)
Org. nitrogen	0.2-0.5(19)	0.2(3)	0.2(3)	DL-0.4(19)	0.2(3)	0.2(2)	0.2-0.4(9)	0.2(3)	0.2-0.3(2)
Ammonia nitrogen	DL-0.10(13)	———	DL(3)	DL-0.02(13)	———	DL(2)	DL(3)	———	DL(2)
Nitrate & nitrite nitrogen	0.20-0.29(19)	0.28(3)	0.27-0.28(3)	0.21-0.32(17)	0.27-0.28(3)	0.27(1)	0.21-0.24(9)	0.28(3)	0.26-0.27(2)
Calcium	13-17(19)	13(3)	13-15(3)	13-19(8)	13(1)	15(2)	13-18(4)	13(1)	14-15(2)
Manganese	3-4(10)	3(3)	4(3)	3-5(8)	3(1)	4(2)	3-4(4)	3(1)	4(2)
Potassium	DL-3(10)	1(3)	1-2(3)	DL-1.4(8)	1(1)	1-2(2)	DL-1(4)	1(1)	1-2(2)
Sodium	2(10)	2(3)	2(3)	1.8-2.3(8)	2(1)	2(2)	2(4)	2(1)	2(2)
Sulfate	3.6-4.1(10)	3.3-4.3(3)	3.9-4.1(3)	3.3-4.2(8)	3.3-4.2(3)	3.9-4.0(2)	3.5-3.9(4)	3.4(1)	4.1-4.2(2)
Chlorine	1.7-2.6(10)	1.9-2.1(3)	2.5-2.8(3)	1.7-2.6(8)	1.8(1)	2.3-2.8(2)	1.9-2.4(4)	2.0(1)	2.8(2)
Cadmium	DL(6)	DL(3)	DL(3)	DL-(4)	DL(1)	DL-0.2(2)	DL(4)	DL(1)	DL(2)
Cr, ug/L	———	DL(3)	DL(3)	DL-34(4)	DL(1)	DL(2)	DL-19(4)	DL(1)	DL(2)
Pb, ug/L	DL(6)	DL(3)	DL(3)	DL(4)	DL(1)	DL(2)	DL(4)	DL(1)	DL(2)
Zn, ug/L	DL(6)	DL(3)	DL(3)	DL(4)	DL(1)	DL-20(2)	DL(4)	DL(1)	DL-20(2)
Cu, ug/L	DL(6)	DL(3)	DL(3)	DL(4)	DL(1)	DL-5(2)	DL-24(4)	DL(1)	DL(2)
Ni, ug/L	DL(6)	DL(3)	DL(3)	DL(4)	DL(1)	DL(2)	DL(4)	DL(1)	DL(2)
Ba, ug/L	DL-0.9(6)	DL(3)	DL(3)	DL(4)	DL(1)	DL(2)	DL(4)	DL(1)	DL(2)
Fe	DL(6)	0.1-0.3(3)	DL(3)	0.1-2.1(4)	DL(1)	0.2-2(2)	0.2-1(4)	DL(1)	1.4-1.7(2)
Mn, ug/L	DL(6)	DL(3)	1.0-1.7(3)	DL(4)	DL(1)	DL(1)	DL(4)	DL(1)	DL(2)
Hg, ug/L	DL(6)	DL(3)	DL(3)	DL(2)	DL(1)	DL(1)	DL(2)	DL(1)	DL(1);0.5(1)
As, ug/L	DL(6)	DL(3)	DL(3)	DL(2)	DL(1)	DL(2)	DL(2)	DL(1)	DL(2)
Oil + grease	DL-2.6(6)	DL(3)	DL(3)	DL(2)	DL(1)	DL(2)	DL(2)	DL(1)	DL(2)
COD	DL-12(6)	7(3)	DL(3)	DL-6(2)	7	DL(2)	DL-6(2)	7	DL-9(2)
PCB, ug/L	DL(6)	———	DL-8(3)	DL(2)	———	———	DL(2)	———	———

[a] All measurements in mg/L except as indicated.
[b] Range of values and, in parentheses, number of samples.
[c] DL - less than laboratory analytical detection limit.
Sampling dates: Before - 13 Oct 82, 23 Nov 82, 11 May 83, 14 Jun 83, 12 Jul 83, 17 Aug 83, 24 Aug 83
During - 26 Sep 83, 10 Oct 83
After - 14 Nov 83

ment zone, than along the other control transect (B). Deposition operations were underway when the samples were taken. As expected, the data indicate some localized turbidity. The 10 October 1983 data show water clarity was very poor along Transects A, B, and C, similar to the previous fall (1982). The same holds true for the samples collected on 14 November, two weeks after operations ceased. Water clarity was poor at all locations, most likely due to stormy fall weather.

Aside from water clarity, there was no measurable change in any water quality indicator before, during, or after the demonstration project. Although some of the sediments deposited at the site were found to contain mercury, only a trace amount was detected in one water sample. None of the other contaminants found at low levels in the dredged material were detected in the water during or after the materials were deposited. In total, the project had little or no effect on lake water quality.

BENTHIC INVERTEBRATES

Sparse populations of benthic organisms characteristic of oligotrophic lakes are generally found in the western end of the Lake Superior basin in locations where pollution from cities and industries have not been an influence (Winter 1971). Sampling prior to the nourishment operation along the transects off Wisconsin Point, which for the most part appears to be isolated from direct impact of the Duluth-Superior ports, reaffirmed that few organisms were inhabiting the near shore zone (Fig. 12).

In addition to being naturally sparse, benthic populations on high-energy Great Lakes beaches are known to change dramatically with seasons of the year. Our Wisconsin Point sampling showed a reduction in the number of invertebrates and number of taxa found in the near shore zone during winter and early spring (Figs. 13, 14).

Unloading operations created some temporary turbidity.

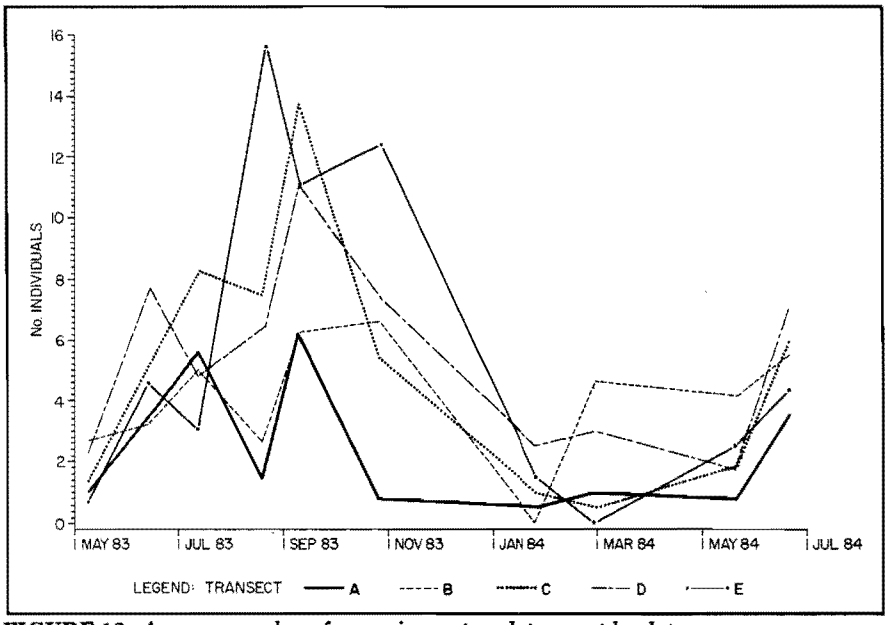


FIGURE 12. *Average number of organisms at each transect by date.*

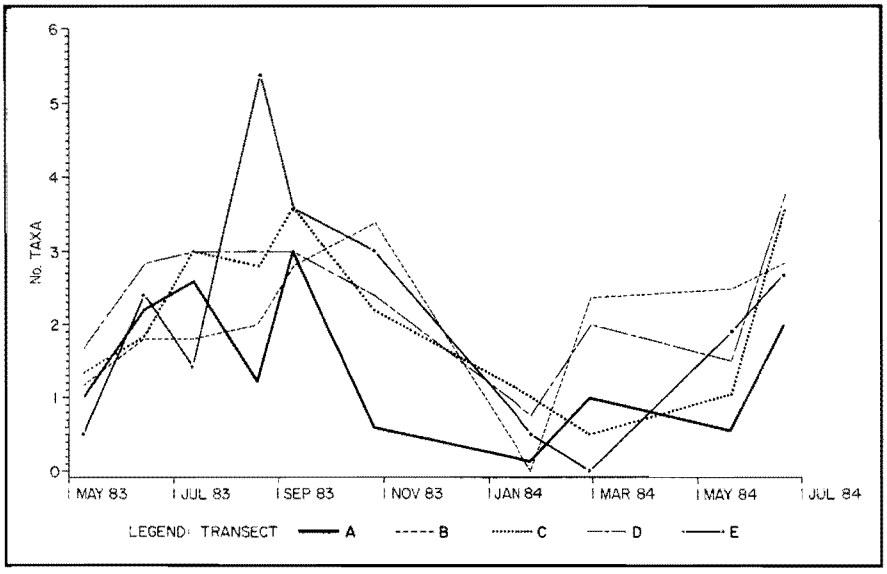


FIGURE 13. *Average number of taxa at each transect by date (Chironomid families separately identified).*

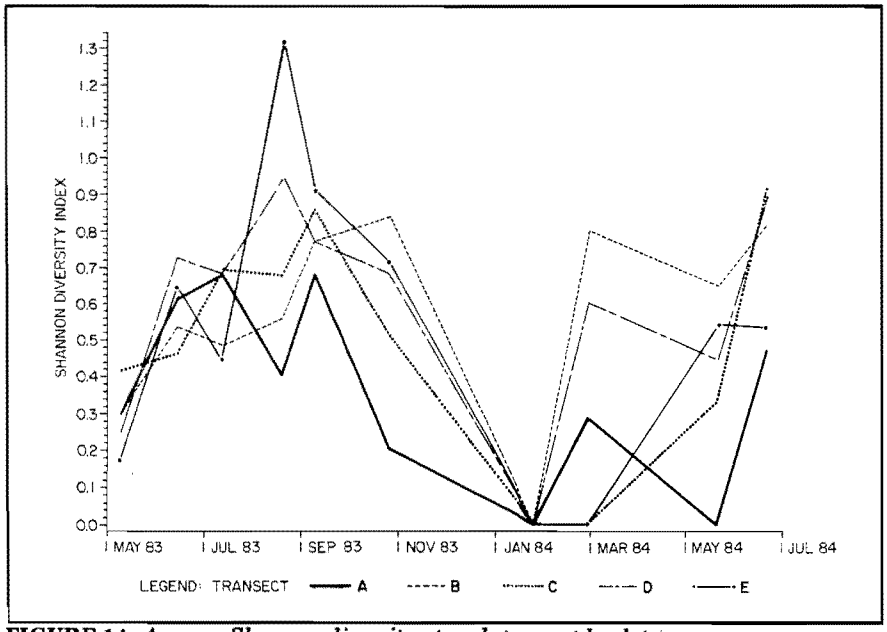


FIGURE 14. *Average Shannon diversity at each transect by date (Chironomid families separately identified).*

Barton and Hynes (1978) found that macroinvertebrate communities which developed along the Canadian shore of Lake Erie in the 0-2 zone during summer, were eliminated by storms and bottom scouring in fall and spring. They speculated that most species probably overwintered offshore and reentered the wave zone by drifting.

Because Wisconsin Point benthic populations are naturally sparse and subject to dynamic changes, major or permanent impacts due to the nourishment project were not documented. Figures 13 and 14 do suggest there were lower numbers, fewer taxa, and less diversity (Shannon Index) along Transect A, in the treatment zone, than along control transects in October 1983 when nourishment operations were nearing completion. However, it appears that by summer 1984, there was no important difference between benthic communities inside and outside the nourished area. The taxa found pre- and post-treatment are shown in Table 6 (Append.).

Comparisons of communities found in May and June before and after treatment on the five sampling transects using Morisita's index of community similarity, as described by Nester and Poe (1982), showed all communities were similar or highly similar (Table 5). This indicated that the project had no long-term impact on invertebrate communities.

Because beach substrate and near shore lake water quality did not show measurable change as a result of the project, it was predictable that the same benthic populations that existed before treatment would become quickly re-established after completion of the project. Brown and Klump (1984) have also reported that the recently completed Kewaunee beach nourishment project had no significant impact on the biological community of the near shore area, and Nester and Poe's Lake Huron study (1982) showed no changes in water quality and benthic organisms.

TABLE 5. *Morisita's index of similarity values comparing benthic communities before and after beach nourishment (Chironomid families pooled).*[a]

Transect	May 1983-1984	June 1983-1984
A	0.5455	0.9137
B	0.5037	0.9511
C	0.9824	0.8960
D	0.7807	0.9596
E	0.7774	0.9789

[a] < 0.500 indicate communities dissimilar, 0.500-0.749 indicate communities similar, 0.750-0.99 indicate communities highly similar.

ECONOMIC EVALUATION

The Corps of Engineers contracted for the Wisconsin Point demonstration project with Durocher Dredge and Dock Co. of Cheboygan, Michigan at a cost of $326,000. With between 50,000-60,000 yd^3 of material handled in the operation, the per-yd cost was $5.40-6.50. During the same period the COE contracted for removal of polluted material from the Duluth-Superior harbor and deposition in a confined disposal facility (CDF) at a cost of $3.75/$yd^3$. However, these figures do not accurately reflect the relative costs of the two operations, because the beach nourishment project probably could have been done less expensively, while the polluted material dredging and disposal operation would have been much more expensive if the costs of the CDF were included. In 1974, the COE estimated costs of CDF disposal were 3-5 times greater than in-lake disposal (Keillor and Ragotzkie 1976).

According to the COE (Court Mueller, pers. comm.), if the Superior harbor "clean" material had been put in a CDF instead of used for beach nourishment, the cost would have been $0.50-1.00/$yd^3$ greater. Further, if bottom-dumping barges could have been used in the unloading operation, approximately $1.50/$yd^3$ would have been saved on the Wisconsin Point project. Bottom-dumping barges require 10-12 ft of water for unloading; therefore, the dredged material was off loaded using a barge-mounted crane in this operation because shallower water (5-6 ft) deposition was specified. This concentrated unloading method created an offshore island and a tombolo developed from westward drift.

SUMMARY AND CONCLUSIONS

Deposition of dredged material in the near shore area resulted in a significant gain of material in the beach and near shore area, which lasted at least until studies were discontinued (7 months). During the post-nourishment period, wave height appeared to be reduced by nourishment fill and waves broke farther offshore than along control areas of the beach. This buildup affected near shore processes and apparently caused additional deposition of material in adjacent beach areas. Hundreds of thousands of cubic yards of new beach material built up to the east of the project site after the project was completed, far exceeding the amount of material used in the treatment. This was caused for the most part by the offshore breakwater effect created by the deposited dredge spoil.

Significant bank erosion took place west of the groin field after dredge spoil was placed. Bank erosion was observed prior to, during, and right after a 17-year storm that buffeted the shoreline about 2 weeks after the nourishment operation was completed.

Thorough sampling of the materials used for nourishment showed that some of them were not suitable for the purpose intended. Some materials were too fine grained, and the first 25 barge loads contained higher than allowable amounts of mercury. However, since laboratory analytical results were not immediately available, there was no way that the use of these materials could have been prevented.

Beach substrate was not altered by the nourishment project. Particle size analysis showed the composition of the bottom remained virtually unchanged during and after the treatment. It is evident that the silts and clays do not nourish the beach because the wave energy moves them offshore into deeper waters. Chemical composition of the beach material also did not change as a result of the operation. No mercury was found in the beach sediments during or after the dredged material was deposited. Since the mercury that was detected in early barge loads of dredged material was associated with fine particles (silt-clay fraction), and the sorting of the finer grain particles occurred rapidly in the unloading operation, there probably was no significant deposition of mercury on the Wisconsin Point beach.

In terms of near shore water quality, aside from some short-term turbidity associated with the unloading activities, there were no measurable adverse impacts. Surveys of the benthic population indicated no detectable adverse impact on the community in the near shore area. Fish habitat was not changed by the project; therefore, fish populations appear not to have been affected in the study area.

Although there was no evidence to show detrimental impacts resulting from this demonstration project, beach nourishment has limited potential at this time as a viable alternative for disposal of significant quantities of dredged sediment from Wisconsin harbors. "Contamination" problems are currently very difficult to define; therefore, only very limited amounts of dredge material can now be classified as truly "clean" and suitable for beach nourishment.

An important result of this project was realizing the need to properly classify harbor sediments for safe use and/or disposal. More extensive testing and analysis of sediments is necessary, and the current EPA guidelines need to be re-examined and revised to more realistically describe and categorize them. We recommend continued investigation into these difficult procedural and classification problems in order that Great Lakes harbor sediments can be used or disposed of in the best and most efficient ways possible.

APPENDIX

TABLE 6. *Taxa found pre- and post-treatment, Wisconsin Point.*

NEMATODA
Unknown spp.

OLIGOCHAETA
Unknown spp.

OSTRACODA
Unknown spp.

COPEPODA
Epischura lacustris
Mesocyclops edax

CLADOCERA
Daphnia galeata mendotae

ISOPODA
Asellus intermedius

AMPHIPODA
Pontoporeia affinis

INSECTA
Ephemeroptera
Hexagenia sp.
Trichoptera
Unknown spp.
Coleoptera
Unknown spp.
Diptera
Ceratopogonidae
Chaoboridae
Chironomidae
Ablabesmyia
Chaetocladius
Chernovskiia
Chironomus
Cricotopus
Demicryptochironomus
Endochironomus
Heterotrissocladius
Microtendipes
Monodiarresa
Orthocladius
Paralauterborniella
Polypedilum
Procladius
Saetheria
Stictochironomus
Tanytarsus
Unknown spp.

ARACHNOIDEA
Hydracarina

MOLLUSCA
Gastropoda
Unknown Spp.
Pelecypoda
Unknown spp.
Empididae pupae

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